OBJECTIVES

Glossary for Cardiovascular Physiology

You are responsible for understanding these terms

Afterload: the resistance against which blood is ejected from the heart. Afterload is estimated from aortic pressure during ejection (left ventricle) or pulmonary artery pressure during ejection (right ventricle).

Arterio-venous oxygen difference: O_2 a - O_2 v

(Note: O_2 = blood oxygen *concentration*, ml oxygen per ml of blood; a = arterial, v = venous).

Capacitance: the volume of a vascular structure.

Cardiac output: the amount of blood pumped from either ventricle in one minute (liters/min).

Cardiac index: cardiac output divided by body surface area (liters / (min x M^2)).

Central venous pressure (CVP): the blood pressure at the entrance to the right atrium.

Contractility: force of contraction

Chronotropic: affecting heart rate.

Compliance: change in volume per unit change in pressure

Diastolic filling time: time available for filling of the ventricles during diastole

Dromotropic: affecting conduction velocity

Ejection fraction: stroke volume divided by end-diastolic volume; an index of contractility.

End-diastolic volume: volume of blood in the ventricle just before it begins to contract.

End-systolic volume: volume of blood remaining in the ventricles at the end of systole.

Extraction: the difference in concentration of oxygen (dissolved plus bound to hemoglobin) or of any solute between arterial and venous blood.

Frank-Starling Law: increasing end diastolic volume leads to increased force of ventricular contraction up to a peak value. Briefly, increased pre-load leads to increased stroke volume.

Heart rate: the number of heart beats per minute

Inotropic: affecting the strength of contraction (contractility) of the heart.

Lusitropic: affecting the rate of relaxation of the heart.

Mean arterial pressure (MAP): average arterial blood pressure; MAP = CO X TPR

Preload: the degree to which the myocardium is stretched just before contraction. Preload is often estimated from CVP for the right ventricle or left atrial pressure (pulmonary capillary wedge pressure) for the left ventricle.

Pressure - volume work: in the heart, work done to pump the stroke volume against arterial pressure.

Pulse pressure: difference between systolic and diastolic arterial pressures.

Vascular resistance: pressure gradient divided by flow; a calculated ratio (not directly measurable).

Stroke volume: the volume of blood ejected by a ventricle in one heartbeat (end diastolic volume minus end systolic volume).

Total peripheral resistance (TPR): the resistance to blood flow offered by the entire systemic vascular bed:

$$TPR = \frac{MAP}{CO}$$

OBJECTIVES

$\dot{V}O_2 = \dot{Q}\ (O_2\ a - O_2\ v)$ In other words, oxygen consumption equals blood flow (Q) multiplied by arterio-venous difference in blood oxygen concentration.

$\dot{V}O_{2MAX}$ = Maximal oxygen consumption (for the whole body).

OBJECTIVES

Introduction

1. Write the Fick equation for diffusion.
2. Explain how cell metabolism creates the concentration gradients for O_2 and CO_2 between the cell and the blood.
3. List four ways that diffusional exchange can increase the amount of material moved.
4. Write the equation relating flow in a tube to the pressure difference across the tube and the resistance to flow.
5. Write Poiseuille's equation for resistance to flow in a narrow tube.
6. Name the class of vessels that provide most of the resistance to flow in the systemic circulation.
7. Define the terms cardiac output, cardiac index, vascular resistance, conductance and compliance.
8. State the normal values for cardiac output, cardiac index, and for resting arterial, venous and intracardiac pressures as given in lecture.
9. Explain the meaning of the term, "total peripheral resistance"
10. Define the terms, systolic, diastolic and pulse pressure.
11. Describe the differences in the velocity of the blood between the large and small arteries, capillaries, venules and veins, and large veins.
12. Be able to write the equations relating
    a. mean arterial pressure to cardiac output and total peripheral resistance
    b. oxygen consumption to blood flow and arterio-venous difference in oxygen concentration
13. Explain how cardiac output may be measured by thermodilution.

Optional reading; one reference is provided for each lecture for those who may want to look further into a topic. No exam questions will be taken from these optional sources except to the extent that the material is also presented in class.

Morton J Kern, Cardiac catheterization techniques: normal hemodynamics. UpToDate (online), 2008

OBJECTIVES

Cardiac Electrophysiology

1. Name the main factor that determines the value of the resting membrane potential (RMP) in cardiac myocytes and give the normal value for the RMP.
2. Explain how comparing the resting membrane potential to the Nernst potential for a given ion reveals
    a. whether or not the ion is in equilibrium across the membrane.
    b. whether the electrical or chemical force affecting the distribution of the ion across the membrane is greater.
3. In the cardiac myocyte, sketch a graph showing extracellular [K^+] on the x axis (ranging from 1 to 50 mEq/L) and approximate values for both the Nernst potential for K^+ and the RMP on the y axis. Explain the significance of the relationship between the two lines.
4. List the four phases of a ventricular myocyte action potential and explain the ion permeability changes and ionic fluxes responsible for each phase.
5. List the permeability changes and ionic fluxes responsible for the pacemaker and action potentials in a sino-atrial node myocyte.
6. Explain what is meant by a latent pacemaker and describe conditions that will reveal its activity.
7. Describe the normal path of electrical excitation in the heart and state how electrical activity spreads between myocytes.
8. List the determinants of conduction velocity in myocytes and Purkinje fibers.
9. Explain the effects on conduction velocity of
    a. The magnitude and rate of rise of the action potential during phase 0.
    b. Changes in extracellular [K^+]
    c. Ischemia
10. Describe the effects of acute and chronic hypo- and hyperkalemia on cardiac and skeletal muscle function as given in lecture.

Optional reading; one reference is provided for each lecture for those who may want to look further into a topic. No exam questions will be taken from these optional sources except to the extent that the material is also presented in class.

Stephen H. Wright: Generation of resting membrane potential, Adv Physiol Educ 28: 139–142, 2004. Reviews basic cell membrane electrophysiology.

OBJECTIVES

The Heart as a pump

1. List four characteristics of cardiac muscle that differ from skeletal muscle
2. Explain how binding of Ca^{++} to tropinin C allows actin and myosin to bind.
3. Describe the sequence of excitation-contraction coupling in cardiac muscle. Include in your description:
    a. T tubules
    b. Dihydropyridine receptors (L-type Ca^{++} channels)
    c. Ryanodine receptors
    d. The SERCA transporter
    e. The sarcolemmal Na^{+} Ca^{+} exchanger
4. Describe the effects of sympathetic stimulation on the rate and force of contraction and relaxation of the myocardium & explain how these effects are mediated within the cell.
5. Create a table for the phases of the cardiac cycle and the four valves of the heart that lists whether a given valve is open or closed for each phase.
6. Be able to recreate a diagram that shows the phases of the cardiac cycle. Include an x axis that is divided into the seven phases of the cycle. Plot aortic pressure, left ventricular pressure, left atrial pressure, central venous pressure, aortic blood flow, ventricular volume, heart sounds, and ECG on the y axis.
7. State the causes of the two primary heart sounds.
8. Describe the Frank-Starling mechanism and draw a graph showing the relationship between end diastolic ventricular volume (x axis) and stroke volume (y axis). Show how the graph is affected by changes in contractility or heart failure. State what measurement represents prload for the right and left ventricles.
9. Define two indices of contractility
10. Draw a pressure volume loop for ventricular function during one cardiac cycle. Label on the diagram the points where ventricular filling, isometric contraction, ejection, and isometric relaxation occur, and when the four heart valves open and close.
11. Be able to use pressure-volume loop diagrams to show the effects on ventricular function of changes in
    a. Preload
    b. Afterload
    c. beta-Adrenergic stimulation
    d. Contractility
    e. Ventricular compliance
12. Explain how changes in sympathetic and parasympathetic activity change heart rate.
13. Name the three determinants of stroke volume.
14. Describe the effect of increasing heart rate on ventricular filling. State the rate above which ventricular filling is compromised.
15. List the three components of cardiac work and state which component requires the greatest oxygen consumption.
16. List four effects of age on cardiac function.

Optional reading; one reference is provided for each lecture for those who may want to look further into a topic. No exam questions will be taken from these optional sources except to the extent that the material is also presented in class.

M. Stefadouros et al, The effect of isometric exercise on the left ventricular volume in normal man. Circulation, vol. 49, p. 1185-1189,1974.

OBJECTIVES

Introduction to electrocardiography

1. Referring to the simple model of the ECG record in one myocyte as presented in lecture, define the isoelectric line and explain how waves of depolarization and repolarization create the positive and negative deflections in the ECG record.
2. Describe the waves and intervals in a normal ECG (lead I) and explain what parts of the cardiac cycle they correspond to.
3. Explain which phases of a ventricular myocyte action potential correspond to different portions of the ECG as shown in lead I.
4. List the 12 leads measured in a standard ECG, state which measure electrical activity in the frontal plane or the transverse plane.
5. Define and state the normal value for the mean electrical axis of the heart. State the effect on the ECG record of a shift in the mean electrical axis.
6. Diagram the axial reference system for the six leads measuring the ECG in the frontal plane. State the normal limits in degrees for the mean electrical axis of the heart.
7. Explain the principle by which the mean electrical axis is determined from the axial reference system.
8. Be familiar with the standard values for calibrating the ECG so that you are able to calculate heart rate and determine intervals between beats on the ECG.
9. Name the three characteristics of a normal sinus rhythm.
10. Define first, second and third degree heart block.
11. Explain how re-entry leads to atrial or ventricular fibrillation.

Optional reading; one reference is provided for each lecture for those who may want to look further into a topic. No exam questions will be taken from these optional sources except to the extent that the material is also presented in class.

S. Meek: ABC of clinical electrocardiography: Introduction. I—Leads, rate, rhythm, and cardiac axis. British Medical Journal vol. 324, issue 16 page 415 – 418.

OBJECTIVES

Hemodynamics & Arterial System

1. Explain the role of the aorta in maintaining arterial pressure during diastole.
2. Explain how differences in the amplitude of arterial pressure wave form occur between the aortic root and the femoral artery.
3. Describe the change in pulse pressure that occurs as blood flows from arteries to veins.
4. List the determinants of pulse pressure.
5. Describe how arterial compliance and pulse pressure change with age, and explain the effect of the changes on cardiac work.
6. Explain why total peripheral resistance is less than the resistance of any individual arterial bed (for example, the renal circulation).
7. Define laminar and turbulent flow.
8. List four factors contributing to the development of turbulent flow, and give three examples of pathological conditions that are likely to induce turbulence.
9. Describe the effects of hematocrit and vessel diameter on blood viscosity. Name two pathological conditions in which blood viscosity significantly affects resistance.
10. Write the law of Laplace relating vessel tension, pressure, and radius.
11. Refer to the law of LaPlace to explain how capillaries resist bursting despite having thin walls, and how pathological dilatation predisposes arteries to rupture and increases the work of the heart.
12. Give the formulas for calculating total resistance for vessels organized in series or in parallel.

Optional reading; one reference is provided for each lecture for those who may want to look further into a topic. No exam questions will be taken from these optional sources except to the extent that the material is also presented in class.

Haddad, H. Feeling Laplace. Adv Physiol Educ, 35, p. 97 – 68, 2011. A simple demonstration of the law of Laplace.

OBJECTIVES

Regulation of arterial pressure

1. Make a diagram showing the baroreflex as a negative feedback loop that senses changes in arterial pressure and produces adjustments in cardiac output and total peripheral resistance that act to restore pressure to the control level.
2. Describe the relationship between arterial pressure and the frequency of action potentials in the carotid sinus nerve.
3. Give the location of the high and low pressure baroreceptors and name the nerves that carry their afferent signals to the brainstem.
4. State the location of the major vascular excitatory and inhibitory centers in the brain.
5. Describe the cerebral ischemic response.
6. Give the pressure ranges over which the different baroreceptors act.
7. Name the veins that are the major capacitance vessels (blood reservoirs).
8. Describe the effects of autonomic failure on baroreceptor function and blood pressure regulation.
9. Explain the mechanism of postprandial hypotension, and of vasovagal syncope.
10. Draw feedback loops showing the interaction between increases or decreases in diuresis and natriuresis, blood volume, and blood pressure (pressure diuresis).
11. Explain the differences between the intrinsic pressure diuresis mechanism and the renal function curve.

Optional reading; one reference is provided for each lecture for those who may want to look further into a topic. No exam questions will be taken from these optional sources except to the extent that the material is also presented in class.

AAJ Smit. Topical Review: Pathophysiological basis of orthostatic hypotension in autonomic failure. Journal of Physiology. Vol 519: p V1 – V10, 1999.

OBJECTIVES

Regulation of the peripheral circulation

1. Explain the role of regulation of arteriolar resistance in the distribution of blood flow among different organs and tissues.
2. Name two differences in the mechanism of excitation-contraction coupling in vascular smooth muscle compared to cardiac muscle, as given in lecture.
3. Make a graph showing the open probability of Ca^{++} channels in vascular smooth muscle cells on the y axis as a function of the resting membrane potential.
4. Describe how vasodilator and vasoconstrictor hormones or drugs act via changes in the activity of K+ channels to affect the tone of the vascular smooth muscle cell.
5. Describe the role of the K_{ATP} channel in linking local metabolic changes to changes in tone of the VSM cell.
6. List three hormones that cause vasodilation by activating K^+ ATP channels, and three hormones that cause vasoconstriction by inactivating K^+ ATP channels.
7. Draw graphs for pressure (x-axis) versus flow (y-axis) for rigid, passive and autoregulatory vascular beds.
8. Explain the mechanisms of myogenic and metabolic autoregulation.
9. For myogenic autoregulation, identify the ion channel thought to mediate the effect of stretch.
10. List five metabolites that may act as vasodilators when their tissue concentration increases.
11. Contrast the mechanism of metabolic autoregulation with metabolic control of blood flow.
12. Contrast the extent and location of sympathetic versus parasympathetic innervation of blood vessels.
13. Name the source for and describe the vascular effect of nitric oxide (NO, EDRF: endothelium derived relaxing factor).

Optional reading; one reference is provided for each lecture for those who may want to look further into a topic. No exam questions will be taken from these optional sources except to the extent that the material is also presented in class.

Mary L. Ellsworth. Eryhtrocytes: oxygen sensors and modulators of vascular tone. Physiology 24:107-116, 2009. A review of recent research about the role of erythrocytes and of ATP in control of the microvasculature.

OBJECTIVES

Microcirculation

1. Name the structures comprising a microvascular unit and indicate which ones are innervated and which contain smooth muscle in their walls.
2. Compare the mechanisms by which water-soluble or lipid-soluble substances and macromolecules are transported across the capillary wall.
3. List the major solutes that determine the value of plasma osmolality.
4. List the four forces (Staring Forces) determining distribution of fluid between the capillaries and the interstitium.
5. Write the equation relating net movement of fluid across the capillary wall to the Starling forces.
6. Name the two components that determine the value of K, the capillary filtration constant.
7. Given appropriate data, be able to calculate net filtration pressure and indicate if the calculated value represents filtration or absorption.
8. List three factors that increase lymph flow.
9. Contrast the effects of changes in arteriolar tone on total peripheral resistance and on capillary hydrostatic pressure.
10. Explain the mechanism that accounts for absorption of interstitial fluid into the circulation as compensation during hemorrhage.
11. Explain 3 mechanisms by which increased filtration changes the balance of the capillary Starling forces to act as safety factors protecting against edema formation.
12. Define “edema” and list five causes of edema.
13. Describe three mechanisms that act as safety factors to limit edema formation.

Optional reading; one reference is provided for each lecture for those who may want to look further into a topic. No exam questions will be taken from these optional sources except to the extent that the material is also presented in class.

MD Delp. Integrative control of the skeletal muscle microcirculation n the maintenance of arterial pressure during exercise. Journal of Applied Physiology. Vol 97: pages 1112 – 1118, 2004. This review expands on the concept that the microcirculation is regulated both locally (metabolic regulation) and centrally (sympathetic nervous system) to balance the competing needs to maintain blood pressure and oxygenation of muscle during exercise.

OBJECTIVES

Venous system

1. List the approximate percentage of the blood volume contained in the different parts of the circulatory system.
2. Describe the factors contributing to resistance in large veins. Include in your description changes in sympathetic activity and anatomical effects (ribs, thorax, viscera, tumors, pregnancy, obesity, ascites).
3. Compare the effects of constriction of the peripheral veins on resistance to venous return and capacitance. State which effect is more important for maintaining cardiac preload.
4. Explain the effect of gravity on the distribution of blood in the venous system above and below the heart, and on capillary pressure in the legs, in the standing position.
5. Give the value for venous pressure the head (sagittal sinus) in an upright person.
6. Explain how venous flow is maintained in the deep veins of the head and neck in the upright position.
7. Describe how changes in the capillary Starling forces protect against edema formation in the upright position.
8. Describe the effect of hypotension on the capacitance vessels.
9. Explain how autoregulation, the balance of Starling forces, and changes in lymph flow protect against development of edema in the legs.
10. Explain how the muscle pump and respiratory movements act to maintain or increase blood flow to the heart.
11. List the four main factors that assist venous return as given in class.
12. List the events in the cardiac cycle that are responsible for generating the venous a, c, and v waves.
13. Explain how left heart failure may lead to right heart failure.
14. Make a flow chart showing how pulmonary and peripheral edema develop in left and right heart failure, respectively.

Optional reading; one reference is provided for each lecture for those who may want to look further into a topic. No exam questions will be taken from these optional sources except to the extent that the material is also presented in class.

BAJ Reddi: Venous excess: a new approach to cardiovascular control and its teaching. Journal of Applied Physiology. Vol 98: p. 356 – 364, 2005. A review that attempts to unravel the relationship between venous return, cardiac output and the Frank-Starling mechanism.

OBJECTIVES

Integrated control of cardiovascular function

1. Define mean circulatory filling pressure and name the two factors that determine the level of MCFP.
2. Describe the effect of increasing or decreasing cardiac output on the distribution of blood volume between arteries and veins.
3. Use values for MCFP, normal central venous pressure (CVP) and cardiac output, to draw a vascular function curve showing cardiac output on the x-axis and CVP on the y-axis.
4. Describe the effects on the vascular function curve, cardiac output, and MCFP, of changes in blood volume or venomotor tone.
5. Make a graph superimposing a normal cardiac function curve on a vascular function curve (to combine the two curves, the x-axis becomes CVP and the y-axis, cardiac output). Explain the physiological significance of the point where the two curves intersect.
6. Show how equilibrium is restored after a change in CVP.
7. Diagram the effect on the equilibrium point of:
    a. An increase in cardiac contractility
    b. An increase in blood volume
    c. Moderate heart failure
    d. Severe heart failure
8. Explain the mechanism whereby CVP remains unchanged or increases when cardiac output increases during exercise.
9. Describe how the equilibrium point changes in patients with heart failure.
10. Describe the effects of atrial natriuretic peptides on afterload in heart failure.

Optional reading; one reference is provided for each lecture for those who may want to look further into a topic. No exam questions will be taken from these optional sources except to the extent that the material is also presented in class.

D Devroey: Signs for early diagnosis of heart failure in primary health care. Vascular Health and Risk Management. Vol 7 pages 591 – 596 2011. An extensive population study aimed at identifying what signs and symptoms readily seen in primary care practice are the best prognosticators of heart failure.